

A REVIEW OF THE ESTIMATION OF KUSKOKWIM RIVER ANNUAL SALMON PASSAGE
THROUGH EXPANSION OF TEST FISHING CPUE

By

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES.....	i
LIST OF FIGURES.....	ii
INTRODUCTION.....	1
METHODS.....	1
Estimation of Tidal Abundance of Salmon.....	1
Assumptions.....	3
RESULTS.....	4
Data 1984-1986.....	4
Number of Tidal CPUE Affected by the Fishery.....	5
Error in the Estimation of CPUE Removed by the Commercial Fishery.....	6
Effect of the Subsistence Fishery.....	8
Effect of Errors in the Designation of Statistical Area of Catch.....	9
Precision of the Estimate of Fish Passage.....	9
DISCUSSION.....	9
CONCLUSIONS.....	10
LITERATURE CITED.....	12

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. The number of fishing periods followed by a response (Yes) or not (No) in the kuskokwim River CPUE by species for 1984-1986.....	13
2. Chinook salmon calibration factor calculations for the Kuskokwim River test fish project.....	14
3. Sockeye salmon calibration factor calculations for the Kuskokwim River test fish project.....	14
4. Chum salmon calibration factor calculations for the Kuskokwim River test fish project.....	15
5. Coho salmon calibration factor calculations for the Kuskokwim River test fish project.....	16
6. Estimate of fish passing the Kuskokwim test fish site; its standard error and approximate 80% confidence interval by species and year.....	17

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. The idealized 7 to 8 tide pattern of test fish CPUE associated with a commercial fishing period on the Kuskokwim River. Test fish CPUE of tide number 1 and 2 occurred prior to the period.....	18
2. Test fish CPUE of chinook salmon for the seven tides associated with each commercial fishing period for 1984-1986. The commercial period lasted for 6 hours following tide number 2.....	19
3. Test fish CPUE of sockeye salmon for the seven tides associated with each commercial fishing period for 1984-1986. The commercial period lasted for 6 hours following tide number 2.....	20
4. Test fish CPUE of chum salmon for the seven tides associated with each commercial fishing period for 1984-1986. The commercial period lasted for 6 hours following tide number 2.....	21
5. Test fish CPUE of coho salmon for the seven tides associated with each commercial fishing period for 1984-1986. The commercial period lasted for 6 hours following tide number 2.....	22
6. The efficiency of the estimate of the calibration factor given a 30% positive (top) or negative (bottom) error in estimating the test fish CPUE removed by the commercial fishery for various levels of commercial exploitation.....	23
7. The efficiency of the estimate of the calibration factor for various levels of commercial exploitation and positive (top) or negative (bottom) errors in estimating the test fish CPUE removed by the commercial fishery.....	24
8. The efficiency of the estimate of the calibration factor for various levels of commercial exploitation and negative errors in estimating the test fish CPUE removed by the commercial fishery.....	25
9. A model of the effect of the subsistence fishery closure on Kuskokwim River test fish CPUE.....	26
10. The efficiency of the estimate of the calibration factor for various combinations of commercial and subsistence exploitation.....	27

INTRODUCTION

The Kuskokwim River test fish project has operated at the current site since 1984 (Huttunen 1985, 1986, Huttunen and Brannian *In Press*). Gill nets are drifted at three stations across the river near the upstream border of statistical area 335-11 beginning one hour after the published high slack tide for Bethel. Two objectives have been to (1) index tidal and daily abundance of chinook, sockeye, coho and chum salmon and (2) estimate tidal and daily fish passage for each species. Methods and results have been reported by Huttunen (1985, 1986) and Huttunen and Brannian (*In Press*). The purpose of this report is to evaluate the success of meeting the project's second objective.

There has not been a formal review of the estimation procedure for fish passage at the Kuskokwim River test fish site nor an evaluation of the precision and accuracy of the resulting estimates. There is also a need to define the assumptions underlying the procedure, test their fulfillment, and evaluate the consequences of their violation. In doing so, criteria can be developed to evaluate the estimation process and the confidence to be placed in the estimate. Often sensitivity analysis is conducted which amounts to the slight adjustment of input values to identify how they affect the resulting estimate. These adjustments are modeled after some theorized variability or error in our ability to measure the necessary input values. In other words, we need to evaluate how sensitive the process is to our choice of input values.

It has been theorized that the catch per unit of effort (CPUE) observed at the test fish site is greatly influenced by the commercial fishery operating downriver. The commercial fishery in statistical area 335-11, when open, includes up to 688 fishermen removing fish throughout a 61.5 mile length of the river. This results in a subsequently known removal of fish, the remainder of whom take from 2 to 4 tides to pass the test fish site. There is a dramatic decline in tidal test fish CPUE following a commercial fishing period.

This report serves to present the assumptions underlying the estimation of salmon abundance passing the test fish site based on the pattern of CPUE surrounding a commercial fishing period. Fulfillment of assumptions are discussed along with the consequences of their violation. It is assumed that the reader is familiar with the project and otherwise should reference the project reports previously cited.

METHODS

Estimation of Tidal Abundance of Salmon

It has been theorized that the CPUE (catch per 100 fathom hour) observed at the test fish site is greatly influenced by the commercial fishery operating

downriver. Figure 1 presents the theorized pattern of test fish CPUE over a 7 or 8 tide period associated with a commercial opening in statistical area 335-11. The pattern of CPUE associated with a commercial fishing period is presented for a building and declining salmon run. The CPUE for tide numbers 1 and 2 was measured prior to the commercial period. The CPUE for tide numbers 3, 4 and 5 are depressed due to commercial removal of a three tide column of fish. If the commercial removal occurred uniformly over the 61.5 mile long statistical area this represents a travel time of 20.5 mi per tide or 41 mi per day. The CPUE of tide numbers 6 and 7 represents fish that entered the river after the commercial opening. The tides following a commercial period vary with the theorized removal by the commercial fleet. They are tide numbers 6 and 7 for a 3-tide removal, tide numbers 5 and 6 for a 2-tide removal and tide numbers 7 and 8 for a 4-tide removal by the commercial fishery.

A calibration factor is needed to expand CPUE to actual fish passage. The CPUE removed by the commercial fleet is estimated as the "column" outlined by a dashed line in fishing period one of Figure 1. CPUE can be related to numbers of fish by equating the known removal in numbers of fish by the fishing fleet to an estimate of the resulting CPUE removed by the commercial fleet. This ratio of catch over CPUE removed by the commercial fleet becomes the calibration factor (F) and is used to expand tidal CPUE to represent fish passage at the site.

The following definitions and conventions are made for purposes of estimating the calibration factor and evaluating the estimator. The symbol $\hat{}$ above a letter means an estimated value is represented and capitals of subscripts represent the maximum values that the subscripts can attain. Many of the project report's variable naming conventions have been adopted for continuity.

J_h = Tidal CPUE of 2 tides prior to ($h= 1,2$) and 2 tides following ($h= 3,4$) those tides affected by a commercial period. Let $H = 4$.

I_k = Tidal CPUE of the tides affected by a commercial fishing period ($k = 1,2,\dots,K$ where $K= 2, 3, \text{ or } 4$). This is the level of CPUE which would have been observed if the fishery had not occurred.

R = Test fish CPUE removed by commercial fishery

F = Calibration Factor

C = Catch of commercial fishery in statistical area 335-11

μ = Exploitation rate of commercial fishery in 335-11

The following relationships are true:

$$(1) \quad R = \sum I_k - \sum (1-\mu)I_k \quad \text{where} \quad \sum (1-\mu)I_k = I_k^{\text{obs}}$$

$$(2) \quad F = C/R$$

Note that I_k^{obs} is the actual CPUE observed at the test fish site on tide k as I_k is not known without an estimate of μ . Parameters of interest are estimated as:

$$(3) \quad \hat{R} = K(\Sigma J_h/4) - \Sigma I_k^{obs} \quad \text{let } \bar{J} = \Sigma J_h/4$$

$$(4) \quad \hat{F} = C/\hat{R}$$

During the season data are analyzed and storied by a unique tide number beginning with 1 at the start of each season. Fish passage (\hat{T}) for tide number n ($n= 1,2,\dots,N$ where $N= 655$ in 1985) becomes the product of that tidal CPUE (L_n) and the average calibration factor for the year:

$$(5) \quad \hat{T}_n = L_n (\Sigma \hat{F}/M) \quad \text{where } M \text{ is the number of calibrations for the year.}$$

$$(6) \quad \hat{T} = \Sigma \hat{T}_n$$

Calculation of the variance for the estimate of the calibration factor (F) and standard error of the season mean calibration factor follows Huttunen (1986). An approximate variance for a given commercial period calibration factor was estimated as:

$$S^2_{\hat{F}} = (-KC)^2 \hat{R}^{-4} S^2_{\bar{J}}$$

using the delta method (Seber 1982) where $S^2_{\bar{J}}$ is the standard error of \bar{J} . A season average calibration factor (F) was used to relate tidal CPUE to tidal fish passage (see equation 5) and its variance was estimated as:

$$S^2_{\bar{F}} = M^{-2} \Sigma S^2_{\hat{F}} + (M(M-1))^{-1} \Sigma (\hat{F} - \bar{F})^2$$

where M is the total number of commercial openings around which calibration factors were estimated. The variance for the total season fish passage became:

$$S^2_{\hat{T}} = (\Sigma L_n)^2 S^2_{\bar{F}}$$

Assumptions

The following are assumptions underlying the estimation of fish passage at the Kuskokwim River test fish site:

1. The only major loss of fish from the system between the time they enter the river and pass the test fish site is the commercial fishery. Other losses might be major spawning tributaries or waterways which circumvent the channel the test fishery monitors.

2. Closure of the subsistence fishery 24 hours prior to through 6 hours

following a commercial fishing period, does not affect the estimate.

3. Commercial catch in statistical area 335-11 is known without error.

4. Commercial exploitation is great enough to depress the level of CPUE at the test fish site and is the sole reason for such a decline.

5. The number of tides affected by a commercial fishing period is known without error (2-4 tide removal).

6. \hat{R} is a "good" estimator of R . This procedure assumes a smooth entry pattern. A linear change in CPUE over the seven tide pattern gives an unbiased estimate of R .

The above assumptions are related, as the first assumption of a closed system also infers that the subsistence fishery has no affect on the estimator. Also the "goodness" of R may be affected by the accuracy of the designation of the number of tides of CPUE affected by a commercial fishing period. Properties of a "good" estimator of R might be an unbiased one with a minimum variance.

All assumptions can be discussed though it may not be known how well they are fulfilled. Instead, the violation of assumptions will be assumed and the consequences will be evaluated through simulation or sensitivity analysis. The first assumption is found to hold with a review of the project report and the project leader's review of USGS maps and aerial surveys of the area, and it will not be discussed further. For the second assumption, it is not known whether management of the subsistence fishery affects the estimate, and a simulation of the effect of various levels of subsistence exploitation will be conducted. For the third assumption, there is speculation of some misreporting of statistical area when fishermen deliver their catch. This will be investigated by assuming various levels of misreporting and evaluating the consequences. In addition, the effect of the level of exploitation on the estimate, as well as the choice of a 2 to 4 tide removal and the smoothness of the entry pattern will be investigated.

RESULTS

Data 1984-1986

Figures 2 through 5 present the actual pattern of CPUE associated with fishing periods over the time for which the project has been operating (1984-1986) by species of interest (chinook, sockeye, chum and coho salmon). One can evaluate whether the pattern observed in real data is close enough to the theorized pattern to confidently use the data to estimate the calibration factor. By definition test fish CPUE must decline dramatically following the opening of the fishery (begin tide 3) and stay depressed for at least 2 to 4 tides before either 1) rebounding to exceed the initial level in the building

half of the run, or 2) falling below the initial level for the declining half of the run. A decision then becomes necessary on the number of tides affected by downriver removals.

Table 1 presents an evaluation of the performance of historical data. In 1984, the pattern of depressed CPUE following a commercial fishing period and a rebounding thereafter was evident for most fishing periods for all species. In contrast, only one fishing period has projected this pattern for chinook salmon in 1985 or 1986, and at most only half of all fishing periods showed this pattern for the other species. The commercial fishery is expected to always depress test fish CPUE after a fishing period. Reasons for this not occurring might be (1) sampling error in the test fish project through a non-constant catchability as due to weather, (2) an uneven distribution of the fleet exerting an unequal exploitation across the 2 to 4 tide column of fish, or (3) a discontinuous pulse-like or unsmooth entry pattern and variable travel time by that salmon species. Most likely the pattern of CPUE is a result of a combination of these factors. There are several things that need to be known in order to determine the effect of fleet distribution, fish entry, and swimming speed on the pattern of test fish CPUE.

Number of Tidal CPUE Affected by the Fishery

The choice of the number of tidal CPUE affected by the fishery, or K in equation 3, is of critical importance to the estimation of fish passage at the test fish site. A range from a 2 to a 4-tide removal has been used to estimate the calibration factor. Several factors interact to create the pattern of test fish CPUE associated with a commercial fishing period. First, the statistical area is 61.5 miles long, and a specified number of days or tides are required after entering the river for fish to pass the test fish site. Swimming speed may vary from 20 to 30 miles per day depending on the species and stage of the run and will therefore take from 4 to 6 tides to pass through the statistical area. Next, superimposed on this moving column of fish is the distribution of the fishing fleet. If exploitation is evenly distributed throughout the statistical area the number of tides affected is merely a function of fish swimming speed. Lastly, test fishing is conducted at a constant stage of the tide and the commercial fishery is opened at 6:00 pm during the chinook and chum salmon season and at 9:00 am during the coho salmon season. How these two schedules superimpose will also affect the number of tidal CPUE depressed by that opening.

In order to accurately determine the appropriate number of tides one needs to know the swimming speed of fish, fleet distribution and the correspondence between the last test fish drift and the opening of the commercial fishery. Aerial surveys to document the distribution of the fleet have been conducted 5 times in the last 3 years, all during the chinook and chum salmon season. On average 82% (range 70% to 91%) of the total effort in the statistical area is concentrated in the upper 26 miles, or half of the district. Fishing pressure in the remainder of the statistical area was so light as not to impact the CPUE observed at the test fish site. This would translate into an

average impact of from 2 to 3 tides given published swimming speeds (see Huttunen 1985 for references) implying a 4 to 6 tide travel time through the statistical area. Add to this the number of hours between the last test fish drift and the start of the commercial opening. In summary, the choice of from a 2 to 4-tide removal could result from a change in fish swimming speed, fleet distribution or the number of hours between the last test fish drift and the beginning of a commercial fishing period.

Unfortunately, estimates of swimming speed do not exist for Kuskokwim River salmon and aerial surveys of fleet distribution are not conducted every fishing period. It is left to the researcher to estimate number of tide removals based on inspection of the 7-8 tide pattern associated with the period of interest.

Estimates of the calibration factor based on differing numbers of tide removals vary greatly (Tables 2-5). Chinook salmon in 1984, for example, did not demonstrate a very strong pattern of depressed CPUE after the first commercial fishing period (Figure 2), and therefore assumption 4 may be violated. Note that the resulting calibrations vary from 390 to 778 fish per CPUE (Table 2). Unless fleet distribution is known for this period it may be impossible to choose between these values. In contrast, period 5 in 1984 for chum salmon appears to be a 2 or 3-tide removal based on inspection of Figure 4. The resulting calibration factors vary from 590 for a 2-tide removal to 376 for a 3-tide removal, a 36% difference. Without some type of verification there is no basis for deciding upon a "most reasonable" value. A choice which merely agrees with other values may be artificially minimizing the variability or downwardly biasing the estimate's variance. Choice of the number of tides must be based on the evaluation of the 7-tide pattern and not calculated for periods not approximating the ideal pattern. Yet even this does not protect against the coincidental effect of entry pattern, swimming speed, and the commercial fishery creating a pattern which indicates an incorrect choice of number of tides.

Error in the Estimation of CPUE Removed by the Commercial Fishery

Test fish CPUE are expanded to represent fish passage at the test fish site. This expansion (equation 5) is based on the estimation of a calibration factor (equation 4) which has at its core the estimate of CPUE removed by the commercial fleet (equation 3). It is assumed that the only estimated quantity is the foregone catch as detected by test fish CPUE (R). This is estimated by equation 3 and assumes a straight line interpolation. The consequences of over or underestimating the CPUE removed by the commercial fleet (R, dashed area of Figure 1) was investigated as it pertained to the estimation of the resulting calibration factor (F). This was modelled by noting that catch can be defined as follows (using previous variable definitions):

$$(7) \quad C = FR = F\mu \Sigma I$$

and when substituted into equation 4, the efficiency by which \hat{F} estimates F can be defined as:

$$(8) \quad \hat{F}/F = \mu \Sigma I_k / (K\bar{J} - (1-\mu)\Sigma I_k) \quad \text{ideally } \hat{F}/F \rightarrow 1$$

As indicated earlier this whole procedure depends on how well $K\bar{J}$ estimates ΣI_k and the error in estimating ΣI_k can be modelled as follows:

$$\Sigma I_k + e = K\bar{J} \quad \text{where } e \text{ is an error term } \sim N(0, \sigma) \text{ and can be}$$

reparametrized such that:

$$e = p \Sigma I_k \text{ and}$$

$$\Sigma I_k + p \Sigma I_k = K\bar{J}$$

and therefore substituting into equation 8 the efficiency of F or the ratio of the estimated to true calibration factor becomes:

$$\hat{F}/F = \mu / (p + \mu)$$

Note that any error in estimating R results in an error in the calibration factor, the magnitude of the error being also related to the exploitation rate (μ) of the commercial fishery. Because the estimated parameter in F is in the denominator the efficiency of F is not identical for negative and positive errors and is not defined when p and μ are equal in absolute value but differ in sign.

When the error in estimating R is held constant, the efficiency of F increases with increasing commercial exploitation (Figure 6), and when μ equals 1 the closest it approaches to the true value is $1/(1+p)$. In Figure 6, the greatest efficiency when $p=0.3$ is 0.77 with $\mu=1$, and even then F is only 77% of F. Any time R overestimates R (a positive error) F underestimates F and fish passage is underestimated. The bottom portion of Figure 6 presents the efficiency of the estimate when there is a negative 30% error in estimating CPUE removed by the commercial fleet (R). In this case the ratio is undefined when $\mu=0.3$ and approaches infinity (very large values) as μ of 0.3 is approached from the positive or negative side. A negative value for the calibration factor is impossible though the estimate is quite often negative (see Tables 2-5). This indicates that negative errors in estimating R do occur and are of a magnitude that exceeds the level of commercial exploitation. Any time R underestimates R, F overestimates F and fish passage is overestimated.

The efficiency of F also decreases as the error in estimating R increases in absolute value for a constant level of exploitation (Figure 7). The relationship for negative errors is more complex as the calibration estimate becomes negative for errors greater than the exploitation rate. For negative errors less than the exploitation rate, the efficiency rapidly decreases with

the increase in absolute value of the error (Figure 8). Levels below 60% resulted in large errors and were omitted from the figures. The estimation procedure is not recommended for periods with less than 60% commercial exploitation.

The error in \hat{R} was assumed normally distributed with a mean of zero. Errors were expected to cancel when the season mean calibration factor was used to expand for tidal and total passage (equations 5 and 6). Unfortunately, as the negative errors in estimating R increases an even larger increase in the error in estimating F occurs. In other words when an error in estimating R occurs in two fishing periods of equal magnitude but opposite in sign (negative and positive) the errors in estimating F do not cancel. The estimate of F with the negative error is larger and there is a positive bias or overestimation of fish passage if the mean is used for those two periods. This procedure only calculates calibration factors for commercial fishing periods which elicit a strong response in test fish CPUE and excludes negative calibration values. This would tend to exclude large negative errors and all those larger than the commercial exploitation rate ($\mu > p$). Even with this protection the procedure may still overestimate fish passage.

Effect of the Subsistence Fishery

The model to estimate fish passage at the Kuskokwim test fish site assumes no effect due to the concurrently operating subsistence fishery. Intuitively this would be the case if the subsistence fishery occurred continuously at a fairly constant level and in fact would merely decrease each tidal CPUE by a fixed proportion. Unfortunately, the subsistence fishery is closed for the period beginning 24 hours prior and lasting until 6 hours following each commercial fishing period. Therefore CPUE of the 7 tide pattern has been subjected to varying levels of subsistence fishery removal. This pattern of varying subsistence exploitation has been modeled in Figure 9 for the 7 tide pattern associated with a commercial opening resulting in a 3-tide removal of fish. In the absence of commercial fishing and under continuous subsistence fishing each tidal test fish CPUE in the model indexes abundance following 4 tides of subsistence removal. The result of the 36 hour closure is a level of subsistence removal varying from 4 tides of exploitation for tide number 7 to 1 tide of exploitation for the CPUE of tide numbers 3 and 4. The exploitation undergone by the moving column of fish is indicated on each diagonal line in Figure 9 and represents the upstream movement during one tide.

The effect a subsistence closure has on estimating the calibration factor is to underestimate the true removal of test fishing CPUE by the commercial fishery (R of equation 3). As discussed earlier, negative errors in estimating commercial removal of test fishing CPUE results in overestimation of both the calibration factor and fish passage. The overestimation increases with increasing subsistence mortality (Figure 10) and has been modeled for a 2.5% exploitation rate per tide resulting in a 9% overestimation to a 15% exploitation rate resulting in an 80% overestimation

when μ is 0.8. The overestimation of fish passage also increases with decreasing commercial fishing mortality for a given level of subsistence mortality.

Effect of Errors in the Designation of Statistical Area of Catch

Any time a fisherman delivers fish to a buyer the statistical area in which the catch was taken needs to be recorded. In the Kuskokwim Area the major buying location is Bethel which is in the upriver end of statistical area 335-11. Tenders also moor throughout the district and purchase fish. Errors could occur if the buyer recorded the statistical area in which he is located and does not attempt to ask each individual fisherman where the catch was actually taken. This would tend to over allocate the District catch to statistical area 335-11, as many fishermen from statistical area 335-12 travel to Bethel to sell their catch. The magnitude of the error in allocating catch to statistical area 335-11 is directly transferred to the over or under estimation of fish passage. For example, an overestimation of 10% in the catch results in a 10% overestimation of fish passage. In addition, any error in estimating catch appears to be approximately additive with the positive error associated with the subsistence fishery closure.

Precision of the Estimate of Fish Passage

Precision of an estimate involves the size of its variance and resulting confidence interval. An approximate variance has been estimated for the season total passage. For illustration purposes, 80% confidence intervals were calculated as if the estimates followed the student's t-distribution.

Estimates of total passage have ranged from 49,589 chinook salmon in 1985 to 976,234 coho salmon in 1984 (Table 6). These estimates reflect the author's designation of the number of tides of fish removed by the commercial fishery and corrections to the database. Therefore, these estimates may differ from those reported by Huttunen (1985, 1986). The standard error associated with these estimates are quite large. The half-width of the confidence interval has ranged from +/- 35% to +/- 233%. Mean calibrations based on sample sizes of less than three (chinook 1985, 1986; chum 1985) result in extremely large standard errors and t-values.

DISCUSSION

Assumptions underlying the estimation of fish passage at the Kuskokwim River test fish site have been identified and the consequences of their violation investigated. It would be valuable to know which are most likely fulfilled and otherwise what type of errors or biases to expect.

Initially the correctness of the number of tides of fish removed by the commercial fleet is unknown. The evaluation, by different people, of the test fish CPUE pattern associated with a commercial period is only a measure of our repeatability and the choice still lacks verification. Additional aerial surveys of fleet distribution related to choice of tides would be helpful. Secondly, the range in magnitude of errors in the estimation of CPUE removed by the commercial fleet is also unknown. Periods for which there was no commercial fishing can be used in simulations to estimate the magnitude of the expected error. For example, the 1986 season was closed for an extended period of time to protect the chinook salmon run. Under normal circumstances two fishing periods could have occurred during the week of June 15. Using these data to estimate calibration factors under a 90% commercial exploitation with an assumed calibration factor resulted in positive errors for sockeye salmon (+4%, +30%) and negative errors for chinook (-38%, -44%) and chum salmon (-14%, -24%). Overall these errors would result in estimates of passage being from 75% to 196% of the true value. This procedure is sensitive to errors in estimating R and a sufficient number of observations are needed to average across for the season calibration factor in order to provide the opportunity for errors to cancel. Even then there may be a positive bias as negative and positive errors in R do not cancel in the estimation of the calibration factor. In other words, the assumption that R is a "good" estimator of R may be violated if a species has a very non-smooth entry pattern. Too few calibration opportunities existed to expand for chinook salmon in 1985 and 1986 and for chum salmon in 1985.

The effect of closing the subsistence fishery beginning 24 hours prior to and lasting through 6 hours after each commercial fishing period is to underestimate the test fish CPUE removed by the commercial fleet which results in an overestimation of fish passage. The magnitude of the error increases with an increase in subsistence exploitation. Huttunen (1985, 1986) has estimated the downriver subsistence harvest by day for chinook, sockeye, and chum salmon. The magnitude of the daily catches prior to a commercial period has ranged from 15% to 40% of that period's chinook salmon catch. This translates into a per tide subsistence exploitation of from 7.5% to 20% of the commercial exploitation. For example, for period 3 in 1985 the subsistence catch was 24% of the commercial catch or 12% per tide. If commercial exploitation was 60% the subsistence exploitation was 12% of that or 7.2%. This would result in a 30% overestimation of fish passage. Daily subsistence catches of chum salmon prior to a commercial period are not substantial. Chum and sockeye salmon subsistence catches are generally less than 5% of the commercial catch for the central 80% of the run.

CONCLUSIONS

1. The pattern of depressed test fish CPUE following a commercial fishing period and a rebounding thereafter has occurred for at best half of the commercial fishing periods by species since 1985. The pattern was evident for only 1 fishing period of the chinook salmon run in 1985 and 1986.

2. The calibration factor should only be calculated for fishing periods which elicit a strong depression of test fish CPUE following the opening and remain depressed for 2-4 tides, rebounding thereafter. In addition, calibrations should only be attempted over the central 80% of the run.
3. Positive and negative errors in estimating the CPUE removed by the commercial fishery (fish not available for detection at the test fish site) do not cancel in the estimation of the calibration factor. The procedure which excludes negative calibration values has a positive bias and will tend to overestimate escapement.
4. The efficiency of the estimator of the calibration factor decreases with decreasing commercial exploitation, and commercial fishing periods with apparent low exploitation should not be used. Only two commercial periods indicated an exploitation rate greater than 60% for sockeye salmon as estimated by the percent of total CPUE removed by the commercial fleet.
5. The effect of the subsistence fishery closure associated with each commercial fishing period is to overestimate fish passage. The positive error increases with increasing downriver subsistence exploitation. This is most apt to be problem for chinook salmon estimation.
6. An error in allocating District 1 commercial catch to statistical area 335-11 results in an equal error in estimating fish passage. In addition this over or under estimation error is approximately additive with the positive error associated with the subsistence fishery closure.
7. The standard error for the estimate of fish passage is quite large for chinook and sockeye salmon. The resulting width of the confidence interval is too large for practical use.
8. Estimation of fish passage is not recommended for chinook and sockeye salmon, and may be positively biased for chum and coho salmon. Estimates of chinook salmon suffer from inadequate sample size and a positive bias caused by the subsistence fishery closure. Sockeye estimates lack precision.

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Table 1. The number of fishing periods followed by a response (Yes) or not (No) in the Kuskokwim River test fish CPUE by species for 1984-1986.^a

Year	Chinook		Sockeye		Salmon Species Chum		Coho	
	Yes	No	Yes	No	Yes	No	Yes	No
1984	4	1	3	3	7	2	7	1
1985	1	4	2	3	3	2	4	4
1986	1	4	2	2	3	2	4	4

^a The response of interest was a 2 to 4 tide drop in test fish CPUE following the commercial opening and rebuilding to near pre-period levels thereafter.

Table. 2. Chinook salmon calibration factor calculations for the Kuskokwim River test fish project.

Period	Commercial	Calibration Factor			Variance for Calibration Factor			
Number	Date	Catch	2-Tide	3-Tide	4-Tide	2-Tide	3-Tide	4-Tide
1984								
1	618	4,778	778	688	390	807,944	1,246,345	216,994
2	621	3,161	438	252	339	30,326	4,511	82,305
3	625	3,018	633	491	347	23,669	90,944	36,332
4	628	2,625	1630	390	244	12,250,317	95,027	25,874
5	702	1,988	194	205	445	479	4,582	374,818
1985								
1	620	3,647	1022	-1478	-2026	392,085	1,438,759	9,032,418
2	624	5,903	-4293	2091	558	115,737,530	25,639,030	149,961
3	627	3,985	435	574	458	20,424	204,948	148,779
4	701	2,887	-353	-397	-489	5,806	22,057	89,247
5	704	1,491	-257	-254	-619	890	2,098	64,642
1986								
1	626	4,038	-1165	-428	-671	480,334	4,975	107,375
2	630	2,021	-708	-307	-640	105,626	126	473,069
3	703	1,688	996	413	827	1,467,392	98,108	2,810,624
4	707	917	-5916	-355	-220	1.89E+09	20,682	7,656

Table 3. Sockeye salmon calibration factor calculations for the Kuskokwim River test fish project.

Period	Commercial	Calibration Factor			Variance for Calibration Factor			
Number	Date	Catch	2-Tide	3-Tide	4-Tide	2-Tide	3-Tide	4-Tide
1984								
1	618	237	13	16	8	20	123	17
2	621	1,813	320	65	54	156,812	447	405
3	625	10,743	517	-1104	-3796	102,976	1,810,916	580,048,482
4	628	10,942	666	640	331	37,160	114,448	12,664
5	702	8,145	485	297	389	14,113	487	26,187
6	705	6,798	512	-7430	-2214	31,620	2.19E+09	34,700,136
1985								
1	620	2,591	154	418	162	3,026	350,132	35,019
2	624	13,821	-420	359	-234	431,430	418,564	76,028
3	627	15,120	204	264	-155	11,986	75,102	10,145
4	701	12,369	475	136	106	1,222,138	15,623	10,422
5	704	9,392	130	202	609	117	1,168	1,015,741
1986								
1	626	20,760	-115	-180	-156	1,514	17,628	23,564
2	630	9,289	64	75	48	429	1,808	467
3	703	9,287	297	129	207	53,796	2,791	64,158
4	707	4,317	1651	306	277	284,090,060	770,784	990,732

Table 4. Chum salmon calibration factor calculations for the Kuskokwim River test fish project.

Period	Commercial	Calibration Factor			Variance for Calibration Factor			
Number	Date	Catch	2-Tide	3-Tide	4-Tide	2-Tide	3-Tide	4-Tide

1984								
1	618	3,656	94	47	36	1,611	302	195
2	621	15,959	195	277	135	12,007	250,087	22,876
3	625	91,681	628	670	761	20,674	89,552	411,236
4	628	67,056	1131	521	483	243,153	2,171	6,877
5	702	69,897	590	376	1490	25,137	9,390	6,492,507
6	705	54,963	698	1110	685	170,517	3,102,582	767,735
7	709	36,440	1395	845	519	803,506	207,895	35,194
8	712	24,269	732	293	734	167,046	9,182	520,506
9	716	18,605	1623	1512	11628	158,606	815,167	4.96E+09
1985								
1	620	9,462	91	63	60	1,891	985	1,714
2	624	30,344	-4357	1874	-917	214,139,952	14,279,931	559,973
3	627	32,757	346	197	1069	22,387	14,839	26,595,085
4	701	26,039	-4031	3377	-8680	173,613,257	197,112,715	1.75E+10
5	704	15,671	429	-1225	-908	37,238	1,659,338	1,985,316
1986								
1	626	33,921	622	222	144	3,201,945	117,673	39,263
2	630	41,842	499	318	187	3,731	7,269	1,866
3	703	40,634	319	145	-411	91,272	6,902	19,006
4	707	30,256	288	153	200	1,816	3,409	26,727
5	710	21,967	168	134	89	6,537	6,530	1,881

Table 5. Coho salmon calibration factor calculations for the Kuskokwim River test fish project.

Period	Commercial	Calibration Factor			Variance for Calibration Factor			
Number	Date	Catch	2-Tide	3-Tide	4-Tide	2-Tide	3-Tide	4-Tide
1984								
10	730	34,563	-1201	504	418	3,484,859	185,888	167,322
11	802	42,363	273	273	-642	8,013	27,334	290,929
12	806	47,384	472	301	231	49,904	15,147	8,441
13	809	42,994	432	349	904	13,073	18,561	811,344
14	813	49,090	1319	520	497	320,092	7,543	15,571
15	816	47,935	342	675	289	8,490	152,874	53,214
16	820	32,439	276	168	164	7,051	944	3,251
17	823	16,904	296	196	168	22,008	8,061	8,180
1985								
6	801	24,962	1539	983	-1609	3,584,606	1,498,269	10,676,397
7	805	36,263	863	282	310	85,626	32,209	90,957
8	808	42,037	1622	1034	204	10,198,885	3,762,602	18,993
9	812	33,019	1306	6535	775	1,680,557	2.75E+09	808,799
10	815	11,095	-3893	-267	-273	264,024,605	18,910	37,071
11	819	8,650	617	555	370	57,457	97,733	37,025
12	822	5,283	382	514	421	18,254	129,038	133,056
13	826	3,787	258	138	132	8,282	9,666	15,717
1986								
6	731	19,775	3208	-116	-239	1.04E+09	202	129,635
7	804	37,784	137	99	88	4,026	3,203	3,435
8	807	61,939	467	318	332	78,890	35,849	77,337
9	811	38,009	188	127	138	3,254	1,386	3,384
10	813	51175	357	212	203	15,485	2,169	3,216
11	815	20946	757	265	114	1,939,420	60,865	3,395
12	818	26324	5467	1620	244	2.24E+09	39,523,049	36,873
13	821	24609	509	228	709	190,325	11,972	1,102,155

Table 6. Estimate of fish passing the Kuskokwim test fish site, its standard error and approximate 80% confidence interval by species and year.

Species/ Year	Number of Fish	Standard Error	Approximate Lower Bound	80% Confidence Interval Upper Bound	% Width of CI
Chinook					
1984	93,543	40,485	31,480	155,607	66%
1985	49,589	16,308	(607)	99,784	101%
1986	83,141	62,983	(110,719)	277,001	233%
Sockeye					
1984	230,918	135,355	(21,655)	483,491	109%
1985	456,125	318,340	(31,890)	944,140	107%
1986	416,396	737,758	(960,260)	1,793,051	331%
Chum					
1984	974,098	243,384	629,709	1,318,487	35%
1985	514,460	171,179	(12,429)	1,041,348	102%
1986	790,343	336,768	274,078	1,306,608	65%
Coho					
1984	976,234	240,585	635,805	1,316,662	35%
1985	606,306	186,293	301,158	911,454	50%
1986	896,498	252,243	533,268	1,259,728	41%

IDEALIZED KUSKOKWIM TESTFISH CPUE

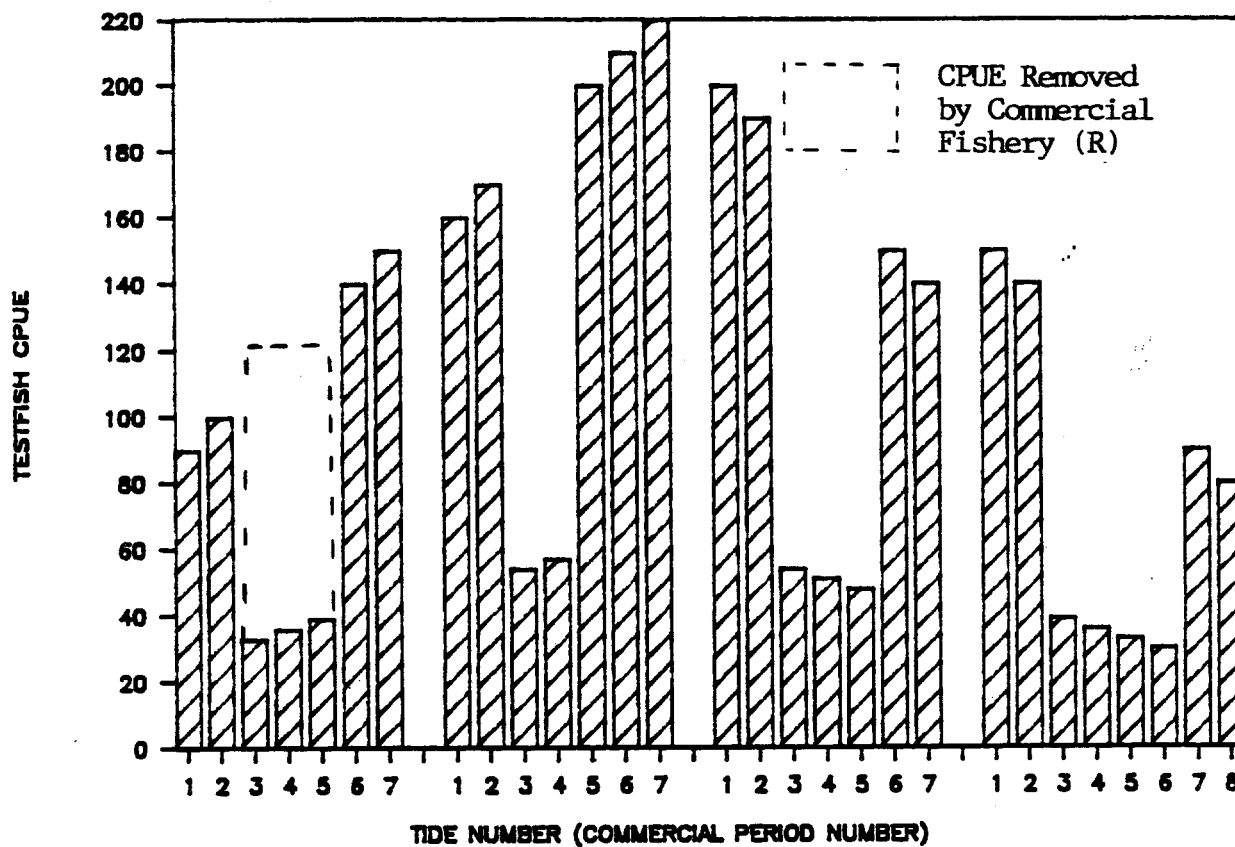


Figure 1. The idealized 7 to 8 tide pattern of test fish CPUE associated with a commercial fishing period on the Kuskokwim River. Test fish CPUE of tide number 1 and 2 occurred prior to the period.

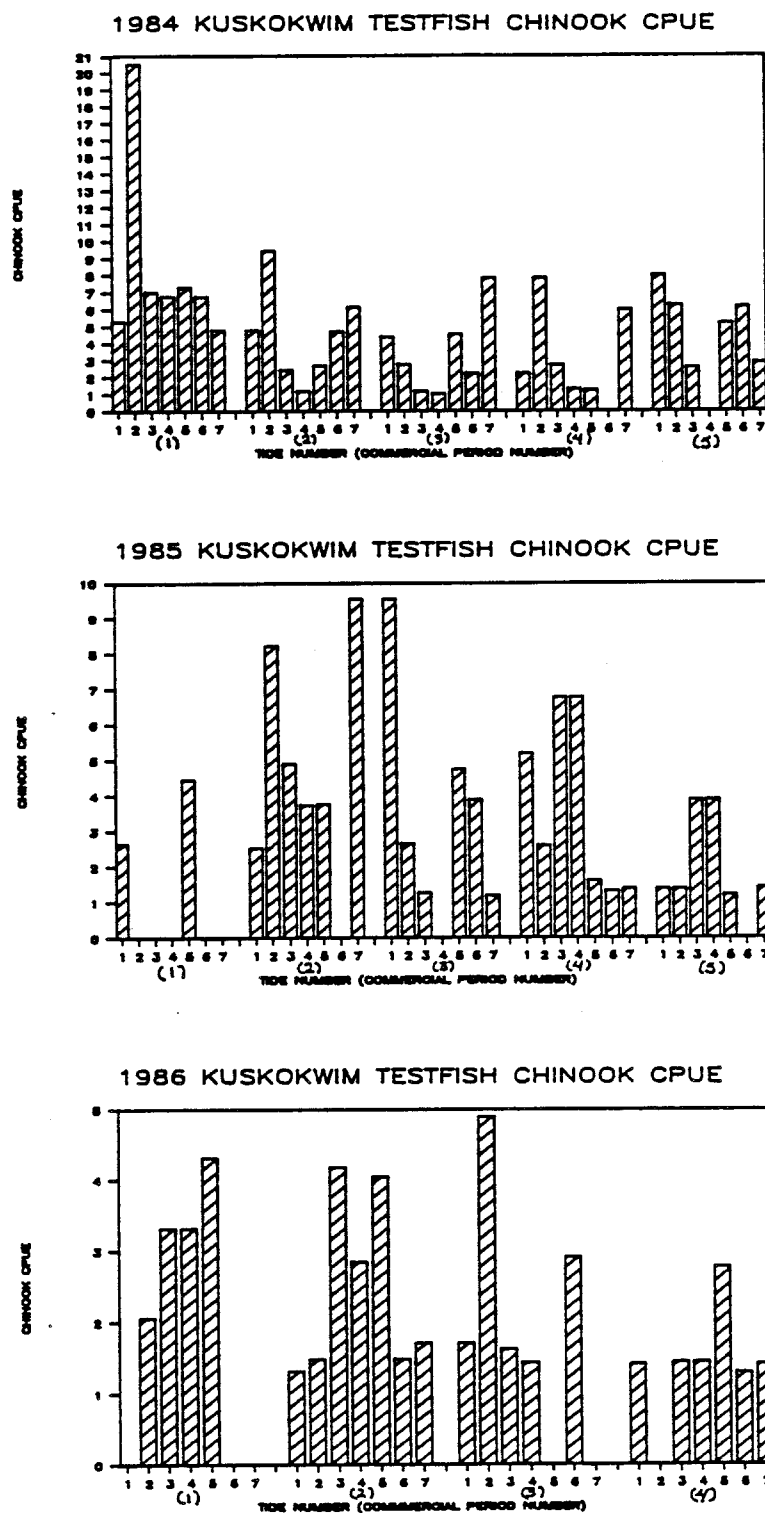


Figure 2. Test fish CPUE of chinook salmon for the seven tides associated with each commercial fishing period for 1984 - 1986. The commercial period lasted for 6 hours following tide number 2.

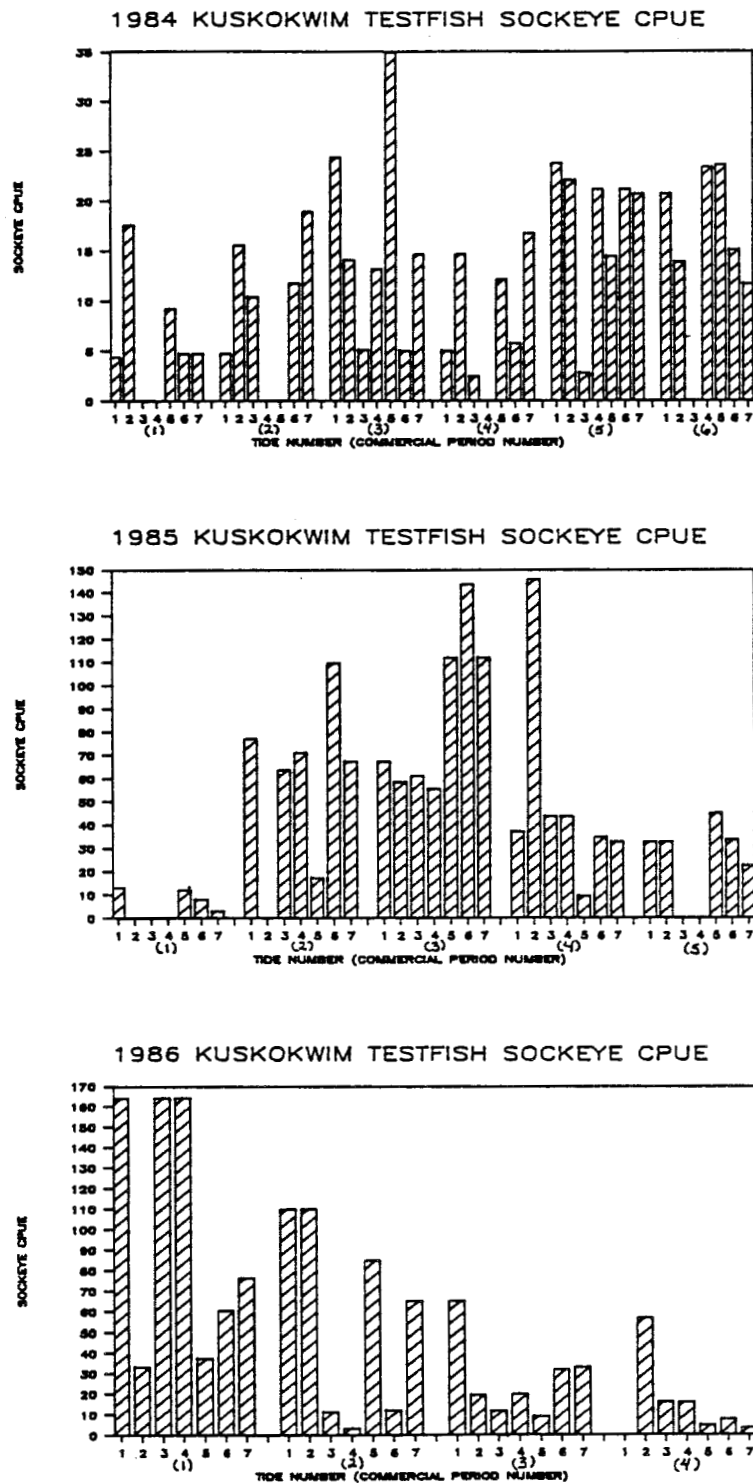


Figure 3. Test fish CPUE of sockeye salmon for the seven tides associated with each commercial fishing period for 1984-1986. The commercial period lasted for 6 hours following tide number 2.

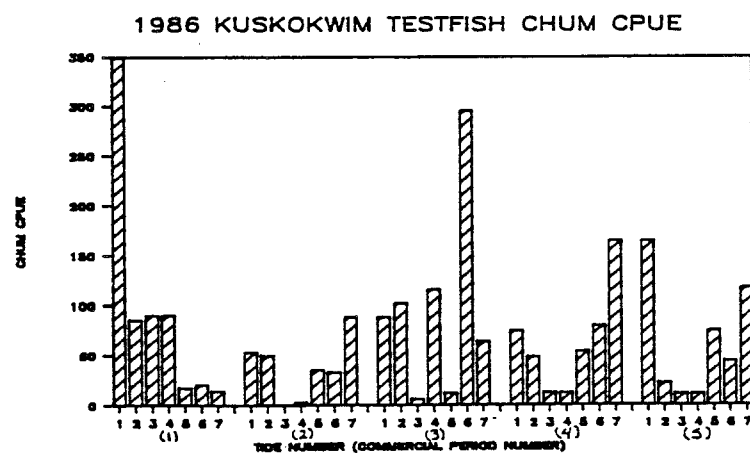
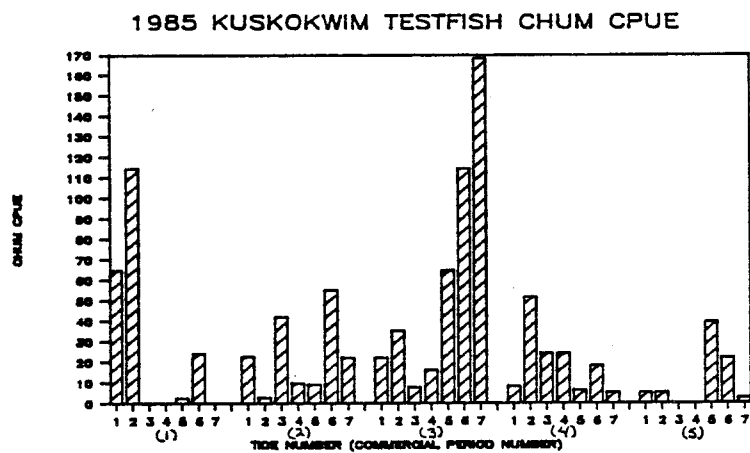
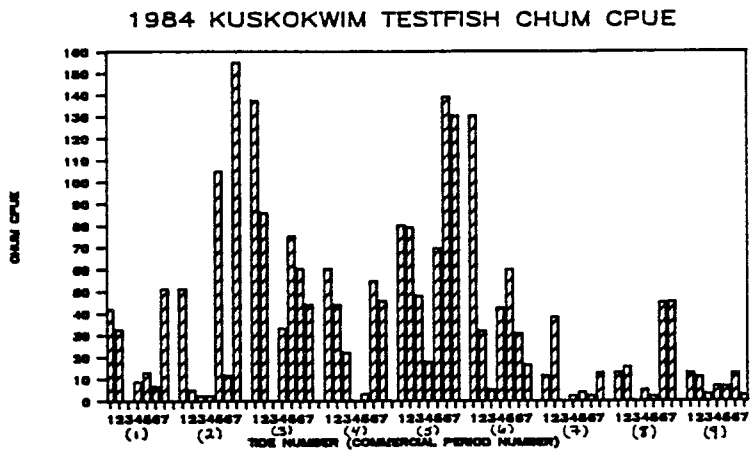


Figure 4. Test fish CPUE of chum salmon for the seven tides associated with each commercial fishing period for 1984-1986. The commercial period lasted for 6 hours following tide number 2.

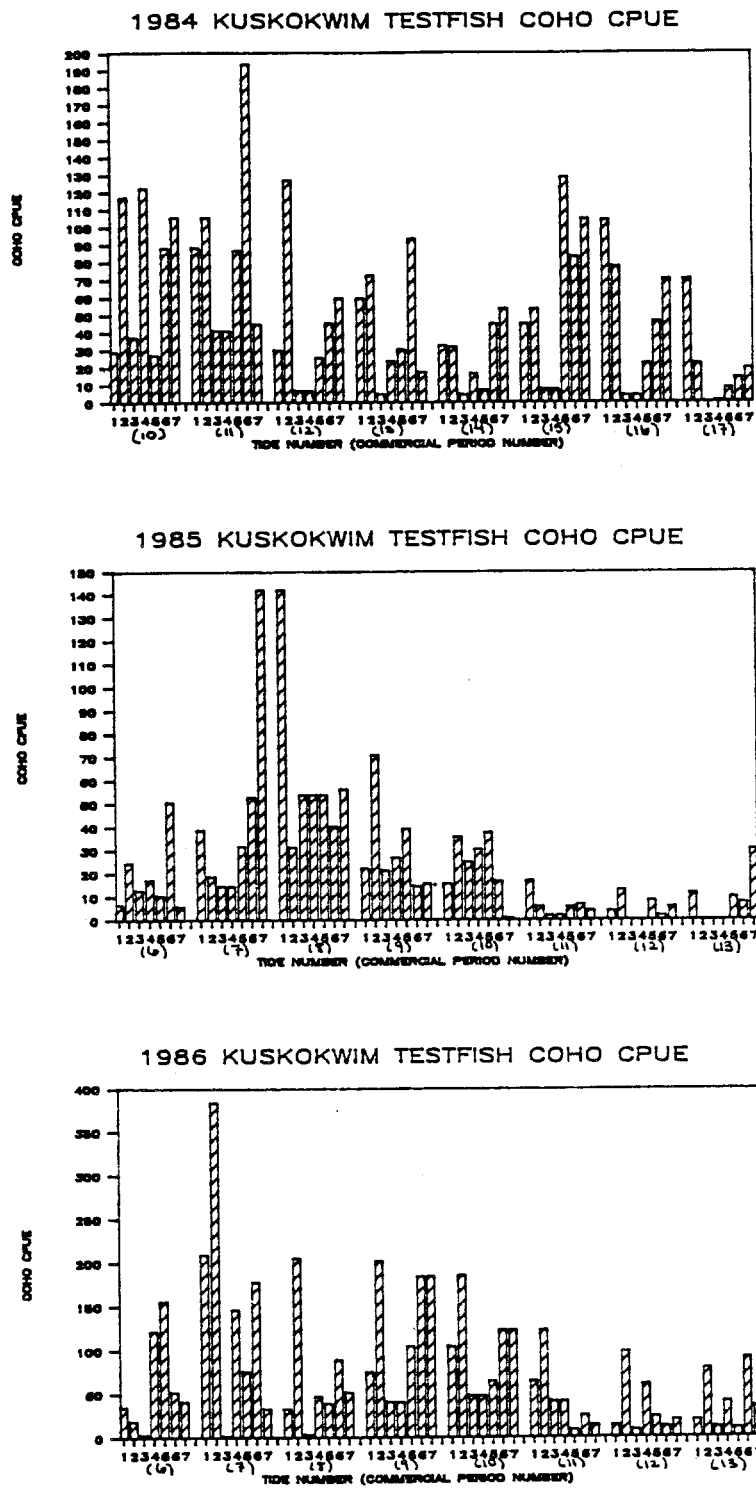


Figure 5. Test fish CPUE of coho salmon for the seven tides associated with each commercial fishing period for 1984-1986. The commercial period lasted for 6 hours following tide number 2.

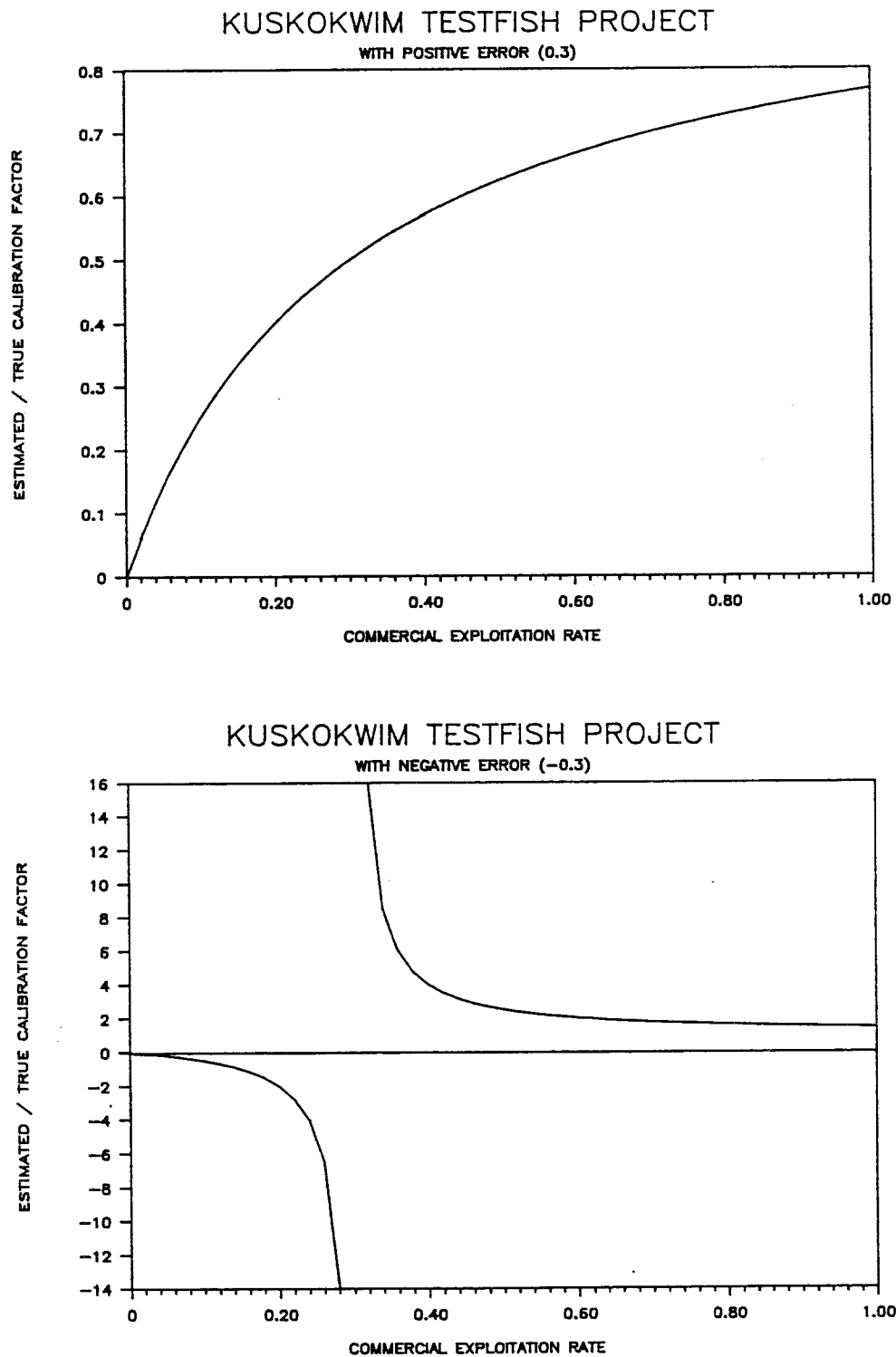
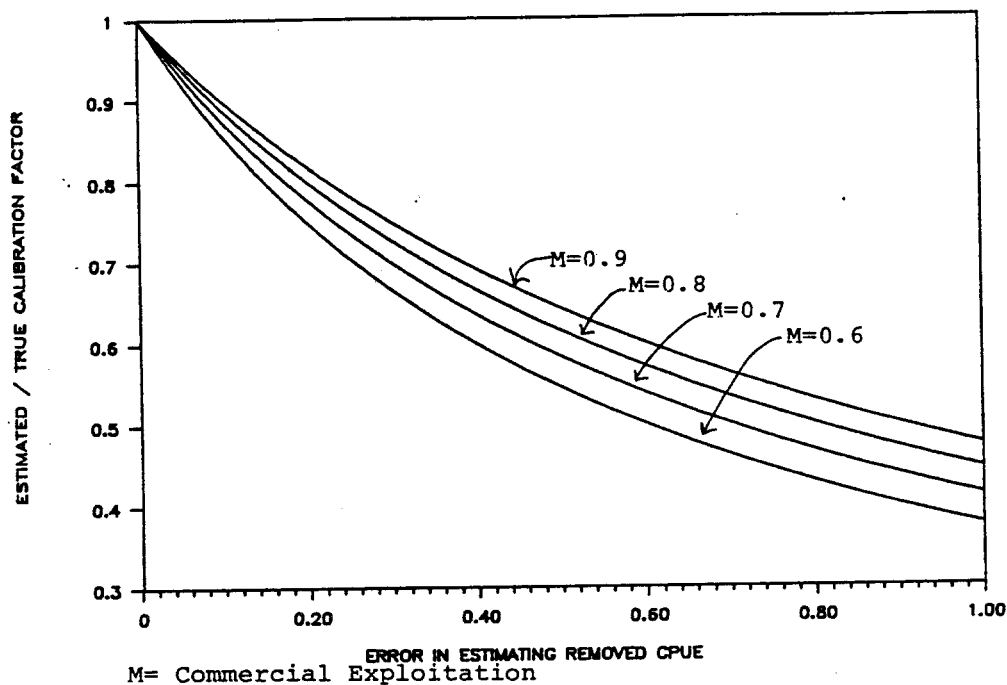


Figure 6. The efficiency of the estimate of the calibration factor given a 30% positive (top) or negative (bottom) error in estimating the test fish CPUE removed by the commercial fishery for various levels of commercial exploitation.

KUSKOKWIM TESTFISH PROJECT



KUSKOKWIM TESTFISH PROJECT

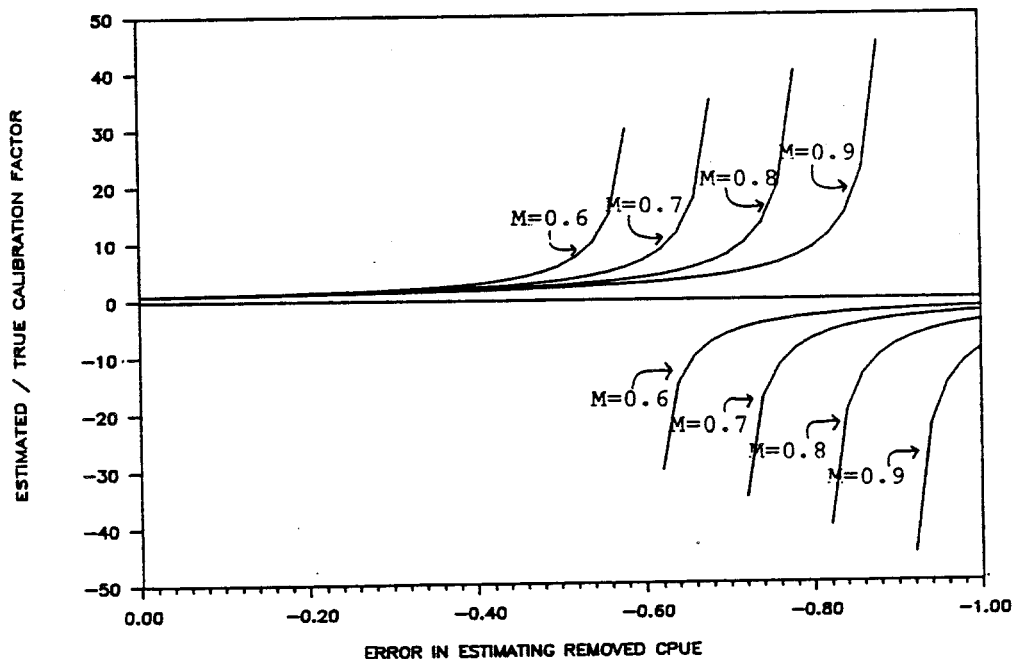


Figure 7. The efficiency of the estimate of the calibration factor for various levels of commercial exploitation and positive (top) or negative (bottom) errors in estimating the test fish CPUE removed by the commercial fishery.

KUSKOKWIM TESTFISH PROJECT

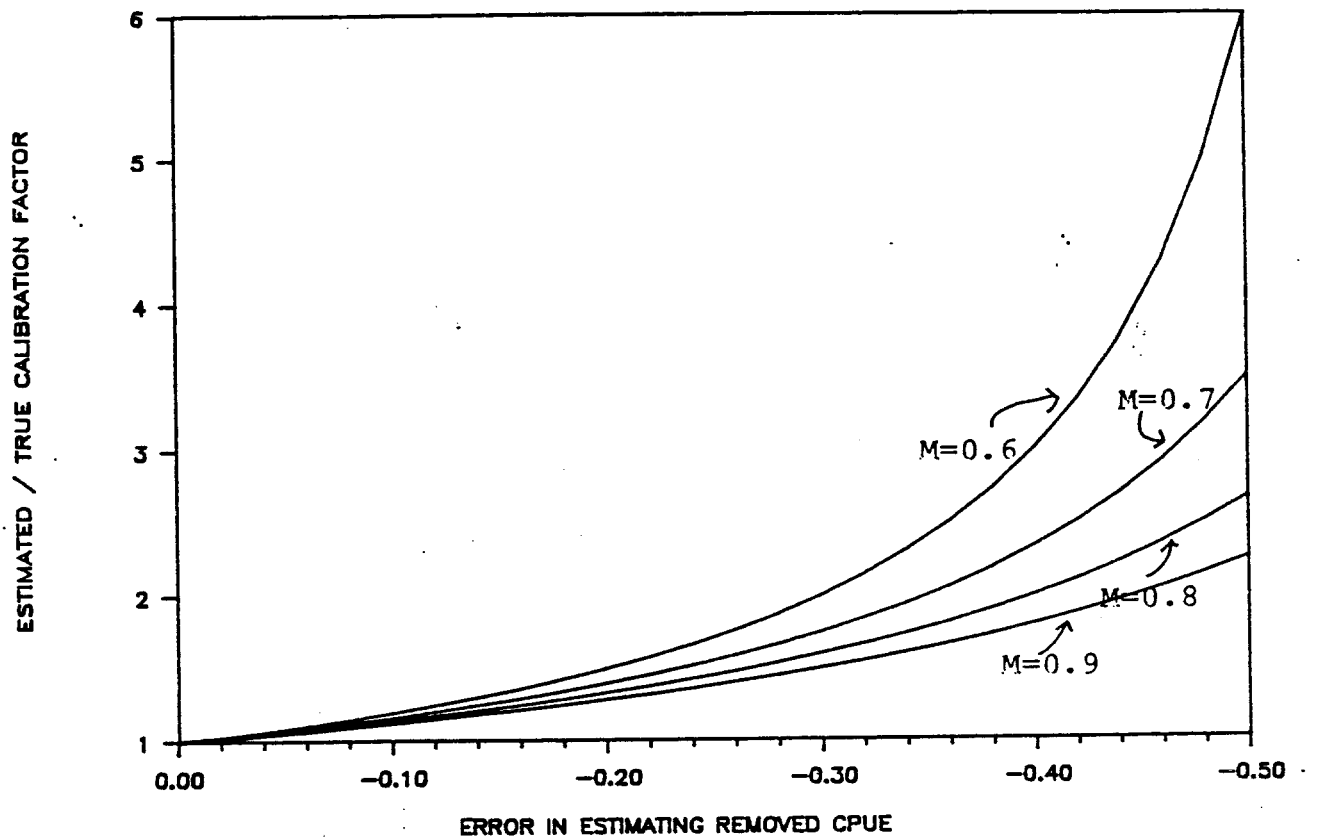
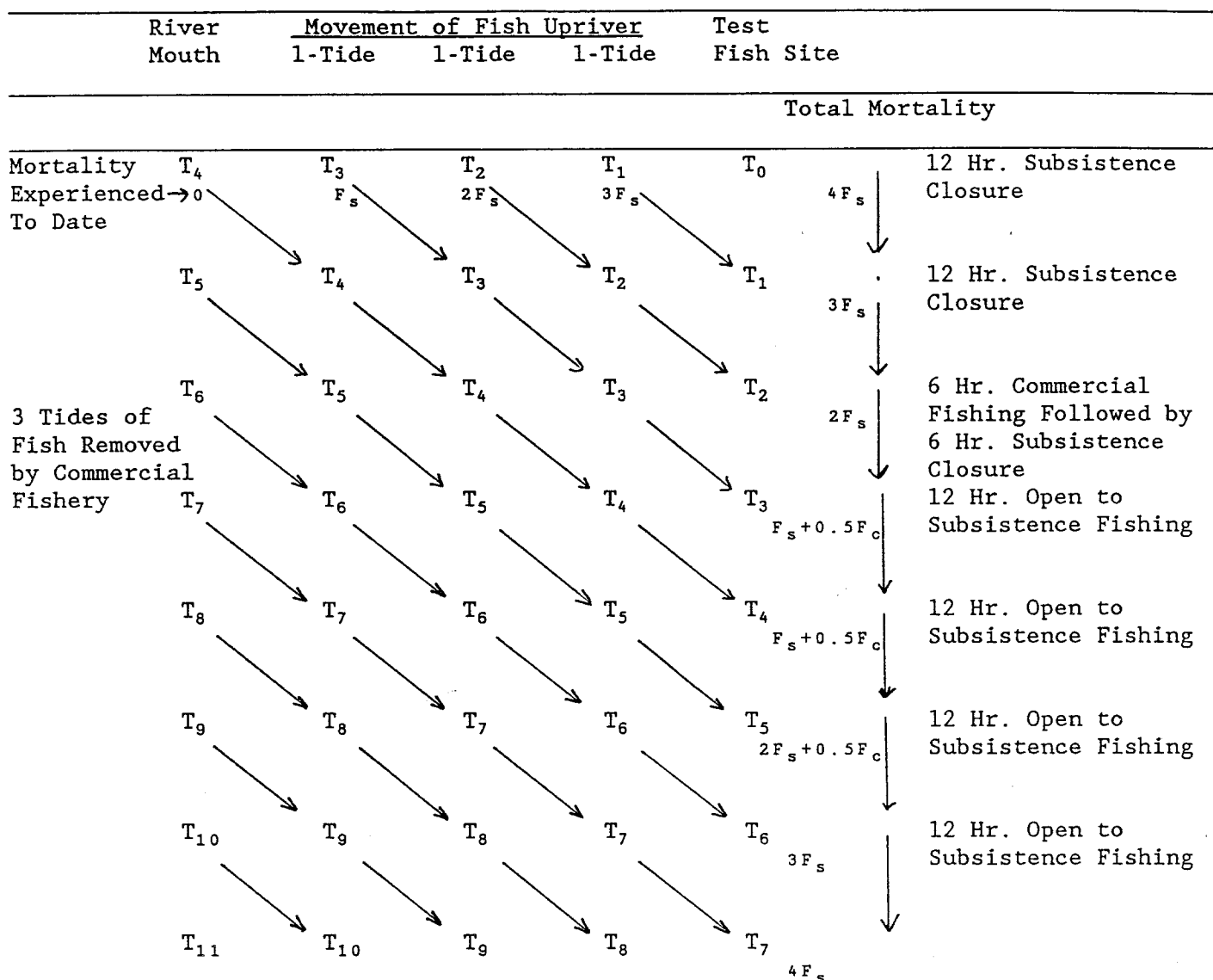


Figure 8. The efficiency of the estimate of the calibration factor for various levels of commercial exploitation and negative errors in estimating the test fish CPUE removed by the commercial fishery.



Where:

- T_i = Tide number i (CPUE of Tide i) $i=1,2,3,\dots$
- F_s = Instantaneous subsistence fishing mortality rate
- F_c = Instantaneous commercial fishing mortality rate
- t = time interval over which mortality occurs $t=1$ per tide
- A = Total mortality = $\mu_s + \mu_c$ = Subsistence and Commercial Exploitation
- $A = 1 - e^{-(F_s + F_c)t}$

Figure 9. A model of the effect of the subsistence fishery closure on the Kuskokwim River test fish CPUE.

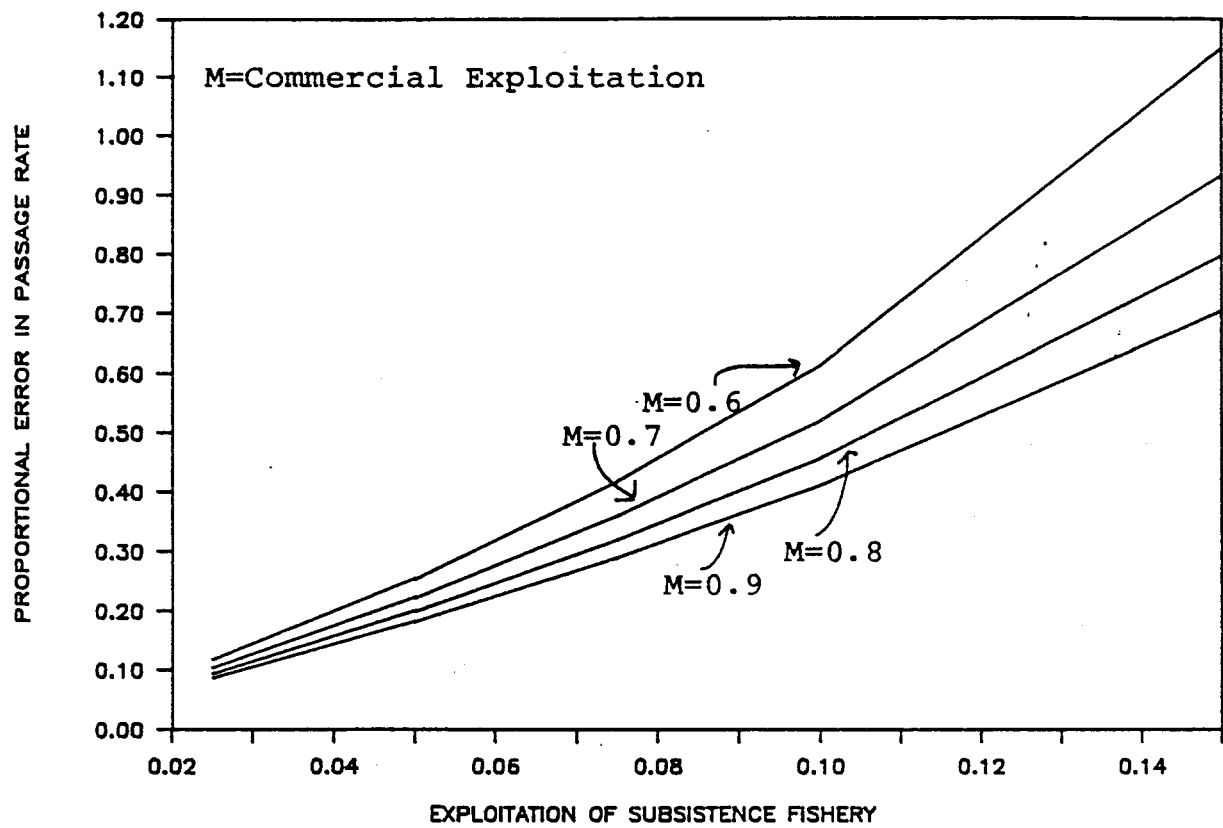


Figure 10. The efficiency of the estimate of the calibration factor for various combinations of commercial and subsistence exploitation.

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